Derivation and control of a spatial Nonlinear Ballbot System

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Abstract

Ballbot is a spherical wheeled robot. It is constructed of a main body which is mounted on a ball, while the ball rolls on the horizontal plane. The two bodies are connected together by a spherical actuator. Ballbot is modeled as a spatial unicycle. It can be very useful in handling chores, while being assimilated among people in work places and at home, as it is mobile, narrow, and a human‘s height. Further it can serves as a transportation device.

This work presents the investigation and derivation of a nonlinear control law for a spatial model of ballbot. The goal is to keep the system at its upright naturally unstable equilibrium point, where the body‘s center of mass positioned on the vertical line above the ball‘s center.

The robot‘s design virtually enables the spherical actuator to perform two functions. On the one hand, it pushes the body upwards to its equilibrium point. On the other hand it rolls the ball in the opposite direction, and positions it underneath the body‘s center of mass. This double action enables the system to be stabilized from a wide span of initial conditions.

Further, this design introduces two main challenges. The first is the modeling of the ball‘s motion on the plane, while considering the non-slip constraint. This motion couples the ball‘s position on the plane and its orientation by a nonholonomic constraint. Modeling this motion is a widely investigated problem. A new innovative concept is used in order to overcome this obstacle. We consider only the motion of the ball‘s center, since its orientation is insignificant to the equations of motion. The second challenge is for the actuator to apply torque in all three directions. This can be solved by considering spherical actuator that is constructed of omni-wheels, that is able to provide these torques. This is an improved drive train to the original CMU Ballbot‘s inverse mouse-ball drive train, in its spatial 3D actuation followed by its reduced redundant friction.

In this work we derive a full three dimensional kinematic and dynamic model of ballbot. Based on the spatial model, a non linear controller is constructed in two parts. The first part is based on the Partial Feedback Linearization method. It is used to stabilize the robot at its upright position. The second part is a PD position controller, used to position the robot at the desired location on the horizontal plane. The Underactuated nature of the ballbot system, as it consists of less actuators then degrees of freedom, presents a major difficulty in the control design.

Computer simulations ware conducted, presenting the controller capabilities of regulating the robot from initial conditions, up to a global angle of about 29 degrees off the vertical axis. Another simulation presents the controlled system‘s trajectory tracking performance. A reduced scale experimental system was built, and the experiments results will be presented.